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UNMANNED LUNAR AND PLANETARY EXPLORATION

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19. LUNAR AND PLANETARY EXPLORATION

GENERAL

Explorer I (Alpha 1958) put the United States into the Space Age on 31 January 1958 when it was launched into orbit carrying a 30.8-pound instrumented payload designed to investigate cosmic radiation, micrometeoroid concentration, and temperatures in the near-Earth environment. Its discovery of the lower Van Allen radiation belt was probably the most noteworthy achievement of the International Geophysical Year.

This historic satellite and others in the Explorer, Vanguard, and Pioneer series gathered a considerable body of knowledge concerning micrometeoroids, radiation and magnetic storms, ion and electronic composition of the ionosphere, and the structure of the Earth's magnetic field and its relationship to that of the Sun.

Earth's profile. Vanguard I, launched 17 March 1958, established a new image for the Earth: a pear-shaped mass with the stem end at the North Pole, contrary to the long-held idea of a spherical planet flattened at both poles.

The United States officially removed the nation's lunar and deep space programs from military cognizance when the National Aeronautics and Space Administration (NASA) was created by Act of Congress in July 1958.

Dedicated to "activities in space devoted to peaceful purposes for the benefit of all mankind", the new agency acquired the facilities of the National Advisory Committee for Aeronautics and five research centers and laboratories throughout the country. Its fields of investigation were to include spacecraft, launch vehicle systems, aircraft, propulsion technology, space power, electronics and communications, and the sciences and technologies associated with human flight in space.

Launch vehicles. In connection with its space exploration programs, NASA has developed launch booster vehicles such as the solid-propellant Scout, the three-stage Delta, and the reliable Thor-Agena B, which is capable of placing 1,600 pounds of payload in a 300-nautical-mile orbit. The Atlas/Agena-B launch vehicle has been the workhorse for NASA satellite programs and for lifting lunar and planetary spacecraft into orbit and injecting them into escape trajectories. This vehicle can orbit about 5,000 pounds at 300 nautical miles, or launch 750 pounds to the Moon.

A new Centaur high-energy second stage, in tandem with the Atlas, will use liquid hydrogen and liquid oxygen for placing 8,500 pounds in a 300-nautical-mile orbit, or launching 1,300 pounds to Venus or Mars.

Saturn, heavyweight of the space vehicles now being developed for NASA, is a liquid-propellant giant capable of one and one-half million pounds of thrust in its early C-1 configuration. Later versions will produce several millions of pounds of thrust, enough to lift a 160,000-

pound space laboratory into orbit, or to inject 40,000-pound spacecraft into trajectories to the near planets.

In its programs of lunar and planetary exploration from 1958 to the end of 1965, NASA has:

- Flown three probes into cislunar space, three past the Moon into solar orbit, one into the region between the orbits of the Earth and Venus, and one into deep heliocentric orbit.
- Impacted one spacecraft on the back side of the Moon and four on its visible side, the last three conducting photographic missions.
- Achieved the first instrumented exploration of deep interplanetary space and near fly-by of Venus.
- Returned the first photographs of Mars from the vicinity of the planet, secured data about the transit regions to that planet, the nature of its atmosphere and its fields and particles environment.

LUNAR EXPLORATION

The United States program of unmanned exploration of the Moon has been assigned to five classes of space vehicles: the Able and Pioneer probes, and the Ranger, Lunar Orbiter, and Surveyor spacecraft. The Jet Propulsion Laboratory, California Institute of Technology, managed the Ranger and Surveyor Projects for NASA; Langley Research Center performs that function for Lunar Orbiter. Table 1 charts the lunar missions flown to the end of 1965.

Table 1. U.S. Lunar Missions

Launch Date	Vehicle	Mission	Results
17 Aug 1958	Able I	Lunar fly-by	Launch failed; turbo-pump bearing out at 74 sec.
11 Oct 1958	Pioneer I	Lunar fly-by	Apogee 70,700 miles; uneven separation of second and third stages.
8 Nov 1958	Pioneer II	Lunar fly-by	Apogee 963 miles; third-stage ignition failure.
6 Dec 1958	Pioneer III	Lunar fly-by	Apogee 63,580 miles; premature first-stage cutoff.
3 Mar 1959	Pioneer IV	Lunar fly-by	Injection velocity low: 37,000-mile lunar miss; tracked to 407,000 miles.
26 Nov 1959	Atlas-Able IV	Lunar orbit	Launch failed; bad shroud.
25 Sep 1960	Atlas-Able VA	Lunar orbit	Launch failed; second-stage malfunction.
15 Dec 1960	Atlas-Able VB	Lunar orbit	Launch failed; first-stage malfunction.
23 Aug 1961	Ranger I	System flight test	Failed to escape Earth orbit.
18 Nov 1961	Ranger II	System flight test	Failed to escape Earth orbit.
26 Jan 1962	Ranger III	Lunar rough landing	Missed Moon by 22,862 miles
23 Apr 1962	Ranger IV	Lunar rough landing	Impacted back side of Moon.
19 Oct 1962	Ranger V	Lunar rough landing	Missed Moon by 450 miles.
30 Jan 1964	Ranger VI	Lunar photo impactor	Precision impact in Sea of Tranquility; television cameras failed.
28 July 1964	Ranger VII	Lunar photo impactor	4,308 high-resolution photos of Mare Cognitum.
17 Feb 1965	Ranger VIII	Lunar photo impactor	7,137 photos of Sea of Tranquility.
21 Mar 1965	Ranger IX	Lunar photo impactor	5,814 photos of Crater Alphonsus.

PIONEER

Other than the abortive launch of Able I in August 1959, the Pioneer series were the first of the U.S. probes launched to investigate cislunar and interplanetary space and to monitor solar radiation and magnetic fields out to 50 million miles.

Pioneer I, lifted on a lunar mission 11 October 1958 by a Thor-Able rocket, reached an altitude of 70,700 nautical miles and made the first determination of micrometeoroid density and the extent of interplanetary magnetic fields. Pioneer II, also flown from the Thor-Able vehicle, reached an altitude of 960 miles before re-entering the Earth's atmosphere on 8 November 1958.

Pioneers III and IV were launched as lunar probes from Juno II vehicles--modified Redstone missiles with clustered, solid-propellant upper stages. The payload and upper stages were spin-stabilized during launch and the payload was de-spun following upper-stage burnout.

Pioneer III reached 63,580 nautical miles on 6 December 1958 and verified the existence of a second radiation belt about the Earth. Pioneer IV, 3 March 1959, approached within 37,300 miles of the Moon.

Pioneer V, launched by a Thor-Able vehicle on 11 March 1960, explored interplanetary space between the orbits of the Earth and Venus, made the first measurements of solar flare effects in space, and established a radio communications record of 22.5 million miles.

Three attempts to launch Pioneer-type lunar probes from Atlas-Able vehicles failed: in November 1959, and in September and December 1960.

RANGER

The Ranger Project for unmanned exploration of the Moon originated from studies conducted by the Jet Propulsion Laboratory (JPL) in 1959 in conjunction with the Army Ballistic Missile Agency and was made an active project by NASA in 1960.

The two basic objectives of the project were: (1) to develop the engineering technologies required to design, build, launch, and operate spacecraft on flights to the Moon and the near planets, and (2) to secure scientific data to aid in the development of manned lunar exploration programs.

During the period August 1961 to March 1965, nine Ranger spacecraft were launched from Atlas-Agena B vehicles. Only seven were aimed at the Moon; five of these missions reached the lunar surface--one on the back side--and the last three transmitted more than 17,000 high-resolution photographs back to Earth.

New Technologies. The problem of flying instrumented spacecraft with high precision to the illuminated face of the Moon and securing good photographs of the surface required the development of new technologies in designing, building, launching, tracking, and guiding spacecraft on a lunar mission. It was necessary to employ three-axis attitude stabilization and control of the Ranger spacecraft in order to "lock" the solar panels on the Sun for power generation, permit the use of a high-gain directional antenna for communications, aim instruments and cameras at precise points on the lunar surface, and orient the spacecraft for performance of trajectory refinement and terminal phase maneuvers.

The unique lunar mission required some means of compensating for the less-than-optimum geographical location of the Cape Kennedy launching area. The spacecraft and second stage are placed in a "parking orbit" about the Earth and the second-stage engine is restarted at a point more favorable for escape into a lunar flight path. The Agena B provided the restart capability, as it will in certain phases of manned missions.

These new concepts required the development of a worldwide network of highly precise tracking stations, with a control center to act as a command post and central data processing point for calculation of trajectories and commands to be transmitted to the spacecraft in flight. These stations were equipped with 85-foot antennas steerable in hour-angle and declination, and precision receiving and recording equipment. The stations were built in the California desert, in South Africa, and in south-central Australia. Located approximately 120 degrees apart around the Earth, the stations provide continuous tracking coverage.

<u>Three Blocks of Rangers</u>. The Ranger program was planned in three blocks or series of spacecraft. The Block I spacecraft, designed for the first two missions, were for engineering-development flight tests only and were not intended to impact the lunar surface. Neither flight escaped Earth orbit because of launch vehicle failures.

The Block II Rangers comprised flights III, IV, and V, and carried a seismological experiment housed in a capsule intended to separate and impact at survivable velocity on the surface, using a retrorocket system. The instrument would then sense and transmit data on disturbances detected in the lunar structure.

All three Block II Ranger flights were unsuccessful in accomplishing their lunar missions because of malfunctions in either the launch vehicles or the spacecraft. The four-mission Block III series was then charged with the primary objective of returning photographs of the lunar surface at least ten times better in resolution than any obtained from Earth-based instruments.

The spacecraft. The principal subsystems of the Block III Ranger spacecraft were power, telecommunications, guidance and control, temperature control, propulsion, and pyrotechnics. The 809-pound spacecraft was constructed around a hexagonal structure which housed three subsystems and supported a television camera payload with transmitters and electronics, a fixed omnidirectional antenna, two hinged solar panels, and a hinged directional antenna for Earth communications.

The spacecraft subsystems were powered by a solar panel system supplying 175 to 200 watts, supplemented by silver-zinc batteries, which were used whenever the panels were not oriented on the Sun, as during maneuvers, or when the solar panel system was loaded beyond capacity.

A telecommunications subsystem consisted of antennas, radio, command, and telemetry units. A three-watt transmitter provided the radio link from the spacecraft, operating through the omnidirectional antenna during the early flight phases and the trajectory correction maneuvers, and through the high-gain antenna when it was locked on the Earth. The telecommunications subsystem included a transponder to receive commands, provide two-way doppler tracking, and transmit the telemetry measurements, which were sampled and encoded by a data encoder.

The command subsystem decoded the signals received from Earth and directed them to the proper subsystem for activation, or to the on-board central computer and sequencer for storage and later initiation of the events.

The attitude control subsystem used sensors for fixing the spacecraft on the Sun along the direction of the roll axis, and optical sensors mounted on the directional antenna for seeking the Earth and orienting that antenna to it. Changes in spacecraft attitude were made with small nitrogen gas jets, activated by the Sun and Earth sensors, and by gyroscopes that detected angular motion about the spacecraft axes.

The spacecraft propulsion system consisted of a rocket motor mounted in the bottom of the basic structure. This monopropellant hydrazine rocket motor produced 50 pounds of thrust and could impart a velocity change varying from 1.2 inches per second to 190 feet per second.

Guidance and control were also functions of the central computer and sequencer and other guidance and attitude control components. Certain commands were stored in the computer before launch; others were transmitted from the ground during flight, based on trajectory calculations, and were stored and implemented at a later time by the computer and sequencer on the spacecraft. A velocity increment sensing system in the computer also shut-off the velocity correction motor at the proper times. These functions were used to implement a trajectory-correction maneuver approximately mid-way in the flight, and a terminal alignment maneuver about one hour before impact.

The Ranger television subsystem, designed and built by Radio Corporation of America, included six cameras, control and video circuitry, power system, and two high-power transmitters, all mounted in the central superstructure of the spacecraft. The cameras had 1-inch f/1 and 3-inch f/2 lenses. Because of potential blurring problems, the cameras had focal-plane, high-speed shutters with exposure times of 1/200 and 1/500 second for full and partial scan cameras, respectively.

Typical Ranger flight. A combination of spacecraft attitude-orientation requirements and constraints imposed by Sun-Moon angles and shadow considerations made the ideal time for launch of a lunar photographic mission a period of five to seven days near the lunar third quarter.

The actual time in which a launch is possible is limited to approximately two hours during the launch period--a "window" made tenable by use of the parking orbit technique. Following separation from the Atlas booster, the second-stage Agena B and the attached spacecraft were placed in orbit by the first firing of the Agena and then coasted over the Atlantic Ocean for a period determined by the time and azimuth of launch and the declination of the Moon.

At the required latitude, the Agena rocket was reignited and reached an acceleration that injected the Agena and spacecraft into a lunar transfer escape trajectory. Following second burnout of the Agena, the spacecraft was separated from the second stage.

About one hour after liftoff, the spacecraft solar panels were deployed and a series of gas-jet maneuvers began which locked the roll axis of the craft on the Sun. Some two and one-half hours later, a similar sequence was initiated to point the directional antenna at the Earth. The transmitter output was then transferred from the omnidirectional to the high-gain directional antenna.

With the spacecraft in its normal or "cruise" mode, the deep space tracking antennas were used to refine trajectory calculations, based on two-way doppler frequency shift measurements. In the case of Ranger, some 10 hours of flight data allowed the lunar impact point computation to reach an accuracy of ±30 kilometers.

After about 17 hours of flight, at a point nearly half-way to the Moon, a trajectory (midcourse) correction maneuver was performed. Computers determined the required velocity change and the attitude to be assumed by the spacecraft while the midcourse rocket motor was fired. Commands were then transmitted to the spacecraft and stored in the computer-sequencer system until the maneuver was to begin. At that time, the appropriate roll and pitch changes were effected by firing the nitrogen gas jets, and the midcourse motor was fired so as to change the velocity increment by the required amount.

This navigation and guidance system was sufficiently accurate that Ranger IX impacted only 5 kilometers (3.1 miles) from the aiming point. Ranger VII was only 15 kilometers (9.3 miles) off target; Rangers VI and VIII impacted within 32 kilometers (20 miles) of their targets.

Following the midcourse correction, the spacecraft was returned to the cruise mode and the attitude geometry was analyzed to determine the nature of any terminal-phase maneuver required to provide the most useful photographs of the lunar surface. The gas jets are used in a three-turn sequence to align the cameras in the desired direction. Of the three successful photographic missions, only Ranger IX actually employed such a maneuver.

The television cameras and vidicon-transmitter system were programmed to switch on about 15 minutes before impact on the lunar surface. Ranger launch times were selected so that the photographic encounter sequence would occur while the spacecraft was in view of the Goldstone, California, tracking station, which provided 100 percent equipment redundancy. The incoming lunar photographs were received and recorded directly on magnetic tape and by exposing 35-mm film to the face of a kinescope.

The target areas for the four flights of Block III were selected for coverage of several types of lunar terrain, some of which were typical of potential landing areas for manned lunar exploration missions. Ranger VI was aimed at the western edge of Mare Tranquillitatis; failure of its television system resulted in a five-month delay in the program. Ranger VII was impacted in a region named Mare Cognitum in honor of the mission, which returned photographs more than 1,000 times improved over the best resolution previously available from Earth. The best of the Ranger VII photographs show craters less than a meter in diameter.

Ranger VIII was also aimed at Mare Tranquillitatis, near the area selected for Ranger VI. Ranger IX, last of the series, was aimed at the crater Alphonsus in order to look at some of the highlands and to seek symptoms of the volcanic action reported in that region by some observers. A small terminal maneuver was performed, yielding the clearest pictures of the entire Ranger series. A close-up examination was made of the central peak and the mysterious dark-haloed craters and rills running across the floor of Alphonsus.

LUNAR ORBITER

The Lunar Orbiter program is scheduled to fly the first of five missions in 1966 as a supplement to the Ranger impactors and the Surveyor soft-landing projects; it will provide extensive photographic reconnaissance of the lunar surface to assist in planning for the Apollo manned exploration missions.

NASA's Langley Research Center directs the efforts of the Boeing Aircraft Company, which is the prime industrial contractor. Facilities of the deep space tracking network and the space flight operations center are provided to support the missions by NASA/JPL.

The Lunar Orbiter spacecraft will be equipped with dual-lens cameras for conducting site examinations and site searches of the lunar surface. The cameras will take high- and medium-resolution photographs simultaneously. Fifty percent or more overlap can be allowed for stereoscopic viewing. The number and rate of camera exposures will be selected from the ground. Picture transmission can only occur during Sun and Earth visibility--about half the time in a mission. The photographic mission life is nominally 30 days.

Liftoff. The spacecraft will be launched by an Atlas-Agena vehicle, placed in a 100-nautical-mile parking orbit by the first firing of the Agena second stage, then allowed to coast until restart of the second stage achieves a lunar transfer trajectory. Explosive squibs will release two pairs of solar panels, an omnidirectional antenna, and a three-foot directional antenna from their launch configuration. The solar sensors will then activate an attitude control system in order to acquire the Sun for spacecraft control in pitch and yaw; a star tracker will lock on Canopus for roll stabilization. Three-axis attitude control will be effected by firing nitrogen gas jets. Gyroscopes will maintain attitude control when the Sun and Canopus are hidden.

The 100-pound spacecraft propulsion system will be capable of two midcourse trajectory corrections. The first will be commanded from Earth about 10 hours after launch, the second at 50 hours, if required.

As the spacecraft approaches within 500 miles of the lunar surface, the rocket engine will be fired in the direction of travel to slow the velocity and place the Lunar Orbiter in a circular orbit above the Moon. This orbit will permit the spacecraft to continually circle the sunrise zone of the surface; while the spacecraft is orbiting, the Moon's rotation will cause different regions to come into the sunrise zone. As the target area reaches this zone, the rocket engine is fired again, placing the spacecraft in an elliptical orbit that will take it into perilune (closest approach) altitudes of 25 to 110 miles. At perilune on each orbit, the photographic sequence will be initiated.

The high-resolution, long-focal-length lens used for site examination, will cover 20 square miles with each exposure, with resolution down to three feet. Site search will be performed with the medium-resolution, wide-angle, short-focal-length lens, which will identify objects down to 27 feet in a 350-square-mile area.

A typical site examination with the high-resolution lens will require seven orbits at a 25-mile perilune, with 20 exposures per orbit and a 2.2-second interval between exposures, covering an area 50 miles on a side.

A site search is made with the medium-resolution lens, covers an area 120 miles on a side, requires 13 orbits from a 25-mile perilune, and makes 14 exposures on alternate orbits only, at 8.8-second intervals, which allows for stereoscopic overlap.

A high-definition, 70-mm film will be used; it is relatively immune to radiation fogging but requires slow shutter speeds. An image motion compensator and velocity/height sensor will reduce image smear.

The photographs will be developed in flight: a damp monochemical process uses a web soaked in developing solution and laminated against the exposed film to produce a high-quality photographic negative. A narrow light beam then scans the negative. The varying light passing through the negative to the face of a photomultiplier tube is converted to electronic signals for transmission to Earth. About 45 minutes are required to readout a single camera operation. When received on Earth, the pictures are displayed on the face of a kinescope and photographed on 35-mm film.

The spacecraft weighs approximately 800 pounds and will use high-reliability, flight-proven components where possible. A communications system provides velocity and ranging signals for ground tracking. Incoming signals are received by the low-gain antenna. Commands are stored in a command decoder, retransmitted to Earth for verification, then sent to the flight programmer for initiation of events. The programmer sequences the commands, which can be stored before launch or transmitted to the spacecraft in flight.

All photographic data and telemetry signals are transmitted through the high-gain directional antenna. The telemetry system will make continuous measurements of the lunar environment and spacecraft system performance. These readings will be transmitted to Earth for as long as 12 months, although the photographic mission will terminate in 30 days.

SURVEYOR

Last of the currently planned NASA unmanned lunar programs, Surveyor will be the first spacecraft designed to soft-land on the lunar surface, photographically survey the immediate vicinity, and transmit the findings to the Earth.

The spacecraft will in effect function as a remote lunar laboratory, controllable from Earth. The primary objective of the missions is to certify potential landing sites for the Apollo Lunar Excursion Module (LEM), to confirm the adquacy of the current LEM design in relation to the environment, and to demonstrate soft-landing techniques on the surface of the Moon. Later, scientifically instrumented versions of the Surveyor spacecraft may be able to explore regions where manned landings are not feasible or practicable.

The Hughes Aircraft Company is contracted as the spacecraft developer, under the project management of JPL. In-flight tracking will be performed by the JPL/NASA deep space tracking stations; computation and control of the mission during flight and after landing will be performed at the JPL space flight operations center.

As conceived in spring 1966, a Surveyor mission will comprise four basic operational sequences: (1) launch, injection, and attainment of attitude-control references; (2) cruise tracking and midcourse trajectory correction maneuvers; (3) terminal descent and soft-landing; and (4) operations on the lunar surface.

The first seven Surveyor missions, now planned through 1967, will carry engineering instrumentation to evaluate both the spacecraft performance and the landing characteristics. A single survey television camera will provide detailed photographs of the immediate landing area. The camera is equipped with a zoom lens, color and polarization filters, is controllable in elevation and azimuth, and has the capability for scanning 360 degrees around the lunar landscape.

Although they have not been definitely scheduled in early 1966, later and more sophisticated Surveyor spacecraft may carry additional instrumentation for extensive scientific experiments. These devices would sample the lunar surface, make chemical analyses, and transmit the data to Earth. A seismometer would sense tremors in the surface resulting from the impact of meteorites or from "moonquakes" caused by internal lunar disturbances. Other experiments may be carried to measure such phenomena as the scattering of alpha particles and the nature and characteristics of micrometeorite ejecta.

<u>Direct ascent</u>. Unlike the Ranger and Lunar Orbiter missions, Surveyor will be launched by the new Atlas-Centaur booster vehicle into a direct-ascent lunar transfer trajectory, without use of a parking-orbit injection technique.

Centaur, first of the new U.S. high-energy vehicles, has two 15,000-pound-thrust engines that burn liquid hydrogen and liquid oxygen. Planning for early Surveyor missions calls for only a single ignition, although Centaur has a two-burn capability that might be used in later flights.

During launch, the spacecraft is protected by a conical, breakaway Centaur nose shroud, which is ejected about 60 miles above the Earth. The legs and antenna support booms are extended at about 100 miles altitude and the spacecraft is separated at the end of the Centaur burn. The Sun and the star Canopus are then acquired for attitude-control reference. Approximately 20 hours after launch, the midcourse trajectory correction maneuver is performed, using the three vernier liquid-propellant engines. Nitrogen gas jets located on the three spacecraft legs are used to effect attitude control during the cruise phase.

Surveyor reaches the vicinity of the Moon after about 66 hours of flight, moving at a velocity relative to the lunar surface of approximately 9,000 mph. About 1,000 miles above the surface, the main retro-rocket thrust axis is aligned with the velocity vector through use of the nitrogen gas attitude-control jets. At 50 miles from touchdown, an altitude-marking radar system triggers the solid-propellant retro-rocket engine, which slows the spacecraft to 350 feet per second at 25,000 feet above the surface. At the completion of the main retro burn, the empty motor case is jettisoned. During this maneuver, the vernier propulsion system and inertial reference unit maintain a constant spacecraft attitude.

After the main retro phase, a radar altimeter-doppler velocity sensor system controls spacecraft descent through a flight-control analog computer. Attitude is adjusted with the vernier thrust chambers and the final velocity is reduced to 15 feet per second vertically and 5 feet per second horizontally at about 13 feet above the surface. At that point, the vernier system is shut off and the spacecraft free-falls to the surface.

Cushioned landing. The Surveyor spacecraft landing is cushioned by landing-gear shock absorbers, crushable footpads, and crushable blocks on the bottom of the spaceframe. After the landing sequence is completed, the solar panel and planar antenna array will be oriented toward the Sun and Earth, respectively. The spacecraft will then proceed to survey the landing area photographically and transmit the pictures to Earth.

The Surveyor spacecraft is a triangle-shaped, three-legged aluminum structure weighing about 2,150 pounds in its initial flight configuration. It measures 10 feet high and occupies a 14-foot circle. The triangle frame has a landing leg on each corner, with an airplane-type shock strut on each tripod landing gear. The structure has been designed with a low center of gravity for soft-landing applications.

The spacecraft propulsion system consists of a solid-propellant main retroengine mounted in the center cavity of the structure for approach slowdown, and a system of three vernier chambers, using liquid propellants, for midcourse correction and the final descent control. One of the vernier chambers swivels for control of the spacecraft in roll attitude.

A vertical mast on top of the spacecraft carries a planar antenna and a solar cell panel assembly. Telecommunications, flight control, and power supply components are mounted in packages around the central frame. Two equipment compartments with heaters and multiple layers of aluminized mylar superinsulation house the system electronics. Selective finishes are used to maintain proper spacecraft temperatures through control of absorption and emission characteristics.

The solar panel is the primary source of electrical power during transit and the lunar day, providing approximately 85 watts of raw power. Silver-zinc batteries, rechargeable by the solar panel, constitute a supplementary power source. Battery charging is automatic, although it may be ground-commanded.

Attitude control is maintained through a primary and a secondary Sun sensor and a star sensor that orients the roll axis to Canopus. An inertial reference unit senses attitude variations during retro-engine operation periods.

The data link to Earth is a wideband telecommunications system, which has two transmitters and two receivers. The transmitters and receivers may be operated during transit in a coherent transponder mode for ground tracking purposes. The high-gain planar antenna array is used primarily for television transmissions.

The spacecraft approach system has an altitude-marking radar, a three-axis autopilot, and a doppler velocity radar. This closed-loop system, working with an on-board analog computer, senses three components of spacecraft velocity relative to the lunar surface and differentially throttles the three vernier engines during the final descent phase. This system is probably the most vital to the successful soft-landing of a Surveyor spacecraft since the tolerances involved in such an operation are precise and critical.

PLANETARY AND INTERPLANETARY MISSIONS

GENERAL

The United States has flown two successful missions to explore interplanetary space and the near planets: Mariner II to Venus in 1962, and Mariner IV to Mars in 1964-1965 (see Table 2). In addition, Pioneer VI was launched into heliocentric orbit on 16 December 1965 to obtain information on solar and interplanetary phenomena; Ames Research Center manages this project for NASA.

Presently planned future missions to the near planets include Mariner Venus 1967, Mariner Mars 1969, and the Voyager Project planned for the decade of the 1970's.

MARINER II

The Mariner II spacecraft made the first scientific measurements in interplanetary space and the first close-in reconnaissance of another planet during the third and fourth quarters, 1962. The Mariner R Project, of which Mariner II was part, originated when it became apparent that the launch vehicle would not be ready in time for the 1962 Venus opportunity.

In summer 1961, the Jet Propulsion Laboratory proposed to NASA that a lighter, hybrid spacecraft based on the Ranger and earlier Mariner designs be built and launched with an Atlas-Agena booster vehicle. NASA authorized the project in September 1961, instructing the Jet Propulsion Laboratory to

Table 2. Mariner Missions to Venus and Mars

	MARINER II	MARINER IV
Launched	August 27, 1962	November 28, 1964
Planetary Encounter	December 14, 1962	July 14, 1965
Accomplishment	First successful Venus mission	First successful Mars mission
Days of Flight Data	129	307
Closest Approach	21,600 miles	6,118 miles
Range at Encounter	36,000,000 miles	135,000,000 miles
Planetary Findings	- Limb darkening - High surface temperature, same on dark as on light side - Clouds cold - no breaks - Negligible magnetic field - No radiation belt detected - No dust belt detected - Mass of Venus accuracy 10 X	- Craters on Mars - 5-10 millibar atmosphere - No ionospheric communication problems in Mars atmosphere - Negligible magnetic field - No radiation belt detected - No dust belt detected - Mass of Mars accuracy 20 X
Interplanetary Findings	- Little dust. 2 hits - Radiation ≈ 3 roentgens - Character of Solar Plasma - Character of magnetic fields	- 215 hits. Dust increased to 1.36 AU, then dropped off. - Radiation ≈ 30 roentgens - Character of Solar Plasma - Character of magnetic fields

develop and launch two spacecraft to the near vicinity of Venus in 1962, to maintain two-way communications, obtain interplanetary data in space, and to perform a scientific survey of the planet.

JPL was given project management responsibility and also system management for the spacecraft, including tracking and space flight operations. The NASA George C. Marshall Space Flight Center had the responsibility for the launch vehicle systems.

Two spacecraft were scheduled from the same launch pad, with 21-day minimum launch separation, in order to increase the probability of success. A 56-day period from July to September 1962 could be used for launch, with only a two-hour launch window available on each of those days. This rigorous schedule had to be met because the planet would not again satisfy launch energy limitations for 19 months.

A demanding task. The schedule called for the system design and development, procurement of components, and the assembly, test, shipment, and launching of two spacecraft in just 11 months. Meanwhile, a concurrent effort was necessary in trajectory computation, launch and space flight operations planning, design and fabrication of ground support equipment, and procurement and preparation of launch vehicles.

Wherever possible, existing Mariner or Ranger hardware and technologies were employed: the basic structure; the solar panels, actuators, and hinge geometry; high-gain antenna and feed; Sun sensor locations and mechanical alignment; Earth sensor; temperature control louvers; and much of the electronics packaging and hardware.

The design characteristics were built around demanding guidelines: a two-way communications capability extending past Venus; a 1:1,000 assurance of not impacting the planet with an unsterilized spacecraft; performance of a trajectory correction maneuver; maintenance of Sun and Earth orientation for communications, environmental control, and the generation of power from solar cells; use of two data rates: 33-1/3 bits per second and 8-1/3 bits per second; and transmission of all data in real time.

Assembly of the spacecraft began in January 1962; system and environmental testing were completed and the two spacecraft and ground support equipment were shipped on 3 June 1962, just 9½ months after project inception.

The 447-pound spacecraft were built around a hexagonal frame of aluminum and magnesium, with a trussed aluminum superstructure. The frame supported the midcourse motors, six subsystem chassis, the hinged high-gain antenna, Sun sensors, and the gas jet system for attitude control. The tubular superstructure supported the solar panels, radiometers, magnetometer, and an omnidirectional antenna at the top. The entire spacecraft measured 5 feet in diameter, 11 feet 11 inches in height, and 16½ feet wide, with panels extended. The science instruments weighed 40 pounds in flight configuration.

The two solar panels supplied between 148 and 222 watts of power and charged a silver-zinc battery that was used before Sun acquisition and during maneuvers and overloads. A three-axis attitude control subsystem stabilized the spacecraft in roll, pitch, and yaw. Sun and Earth sensors operated with gyroscopes and internal logic circuits to actuate cold-gas valves.

Timing, sequencing, and computational and storage functions were provided by a central computer and sequencer (CC&S), which controlled spacecraft events in launch, midcourse propulsion, and encounter sequences. Measurements provided by spacecraft sensors and science instruments were processed by a data encoder for transmission to Earth.

Only engineering data was transmitted during the launch phase, both engineering and science during the cruise phase (before and after trajectory correction maneuver), and only planetary science data during the encounter with Venus.

The telecommunications subsystem provided the capability for receiving and decoding Earth-originated commands, transmitting data from the spacecraft (using only three watts of radiated RF power), and for measuring spacecraft angular position and radial velocity. A phase-shift keying technique was used for modulating the radio carrier with telemetry data. In this system, coded signals from the sensors displaced other signals of the same frequency but a different phase. These phase shifts were translated on Earth into voltages, temperatures, intensities, and other values for measuring spacecraft performance.

The radio command signals were decoded in a command subsystem, then processed and routed to the proper using subsystems and circuits. Mariner II had four antennas: (1) <u>for transmitting</u>--an omnidirectional antenna at the top of the superstructure, which was used from injection through Earth acquisition and during spacecraft maneuvers; and a high-gain directional antenna hinged for position up-dating and used after Earth acquisition; (2) <u>for receiving</u>--two command antennas, one on either side of one of the solar panels, used to receive Earth commands, and for both receiving and transmitting in measuring velocity and position in a two-way doppler mode.

The midcourse rocket engine weighed 37 pounds and developed 50 pounds of thrust. Suspended in the central cavity of the hexagonal structure, its thrust axis was along the roll axis of the spacecraft. The engine used anhydrous hydrazine, which was stored in a rubber bladder and expelled by the pressure of nitrogen gas into a combustion chamber, where nitrogen textroxide acted as a starter and aluminum oxide as a control catalyst. Gyroscope-activated jet vanes in the rocket exhaust stream controlled the spacecraft during motor burn.

The temperature control subsystem used paint, aluminum sheet, gold plating, polished aluminum, and movable louvers to protect the spacecraft components. High-power electronics cases were coated with a radiating white paint; low-power devices used polished aluminum shields.

Off to Venus. Mariner I was launched at Cape Canaveral on 21 July 1962 and was destroyed after about 293 seconds of flight when flight-path deviation threatened to carry it into the North Atlantic shipping lanes.

Following several countdown delays, Mariner II successfully lifted off the launch pad on 27 August 1962. Although the Atlas went into a negative roll, it recovered in time for successful separation of the second stage. The Agena first burn achieved a 115-nautical-mile parking orbit; after 290 seconds of coasting, the second burn injected the Agena and spacecraft into a Venus transfer trajectory over the South Atlantic Ocean, approximately 26 minutes after liftoff.

Separation of the Agena and Mariner was normal. At 44 minutes after liftoff, the solar panels and high-gain antenna were extended on command from the spacecraft CC&S. Sun acquisition took only 2½ minutes; initial solar panel power output was 195 watts, slightly higher than anticipated.

On 29 August, the power system appearing normal, the cruise science instruments were turned on. Earth acquisition was initiated on 3 September, requiring 29 minutes. The brightness reading was such as to indicate that the Moon might have been acquired accidentally; therefore, the scheduled trajectory correction maneuver was postponed. On 4 September, it was estimated that the Venus miss distance, with uncorrected trajectory, would be 384,000 kilometers (239,000 miles) from the leading edge of the planet.

Following successful accomplishment of the maneuver, which used three stored and two real-time commands, this projected miss was corrected to approximately 41,000 kilometers (25,476 miles) and the flight time was estimated at 109.546 days (to closest approach). After the maneuver, the Earth was reacquired in about 30 minutes, the Sun in seven.

On 8 September, an anomaly occurred in which the gyroscopes were automatically switched on and cruise science off. This event could have resulted from impact with an unidentified object, causing temporary loss of Sun lock. The anomaly was observed again on 29 September. On both occasions, the spacecraft recovered normal cruise operations without a plausible explanation.

One solar panel was shorted-out on 31 October and cruise science was turned off to conserve power. On 8 November, the panel returned to normal and the science instruments were restored to operation. The panel was permanently lost on 15 November but the power from the one active panel proved sufficient for both cruise and encounter modes for the rest of the mission because of the approach to the Sun.

By mid-November, spacecraft temperatures were causing considerable concern; 7 of 18 temperature measurements had gone off-scale at encounter and the Earth sensor brightness had dropped off alarmingly. However, all science experiments were operating properly, tracking station coverage was near normal, and signals were clear and data quality good.

Mariner II approached Venus from the trailing edge on 14 December 1962. The encounter sequence, initiated by radio command after a CC&S failure, lasted about seven hours; it was terminated by Earth command.

The radiometers began to scan the planet 65 minutes before closest approach; three scans of the disk were accomplished in 42 minutes. At closest approach, 19:59:28 GMT, Mariner II was 34,854 kilometers (21,645 miles) from the planet, traveling at a velocity relative to Venus of 6.743 kilometers per second (4.19 miles per second). Distance from Earth was 57,785,000 kilometers (35,907,000 miles), from the Sun: 107,577,000 kilometers (66,834,000 miles).

The spacecraft was returned to cruise mode after the encounter and all subsystems performed essentially as before. Temperatures continued to rise and were not expected to decrease until perihelion on 28 December. The spacecraft was last tracked at 07:00 GMT, 3 January 1963, by the South African station. At that time, Earth distance was 86.677 million kilometers (53.860 million miles); distance from Venus: 8.994 million kilometers (5.588 million miles), and from the Sun: 105.857 million kilometers (65.778 million miles).

<u>A new image of Venus</u>. The scientific experiments carried on Mariner II were of two functional types: (1) the interplanetary and near-Venus instruments: magnetometer, high-energy charged particle detector (comprising an ionization chamber and Geiger-Mueller radiation counters), cosmic dust detector, and solar plasma detector; (2) the planetary experiments: microwave radiometer and infrared radiometer, both mounted on the same scanning structure so as to obtain a "stereoscopic" reading of the same regions of the planet during encounter.

Although analysis of the data gathered from Mariner II will continue for years, some preliminary findings can be indicated:

- Interplanetary space is rarely if ever free of magnetic fields, which demonstrate a strong correlation with the flow of plasma or solar wind, with variations roughly corresponding to the 27-day rotational period of the Sun.

- A measurably large flow of plasma was constantly present, always moving at supersonic speeds of 200 to 500 miles per second.

- Only two definite cosmic dust hits were recorded during the mission. The suggestion is that the concentration of small dust particles near Earth is ten thousand times greater than in the regions traversed by Mariner.

- At encounter, the solar plasma flux did not disappear, as in the magnetosphere of a planet, and there was no clear evidence of the spacecraft passing through a bow shock wave. Furthermore, the mean counting rate of charged particles during encounter was significantly less than before or after. This evidence does not necessarily mean that Venus has no magnetic field, but rather that it does not apparently extend out to the trajectory of Mariner. The phenomena normally associated with a geomagnetic field would be modified or completely missing (e.g., trapped particles in radiation belts, aurorae, and cosmic ray flux like that at the Earth's poles distributed everywhere at the top of the Venusian atmosphere.).

- The three scans of the microwave radiometer (at 13.5 and 19.0 mm) showed no significant differences in temperatures on the light and dark sides of the planet (estimated at 460°, 570°, and $400^{\circ}K$, on the dark, terminator, and light sides, respectively). The cooler temperatures along the edges or limbs suggest a limb-darkening effect, ruling out the likelihood of Earth-like temperatures at the surface, which is estimated at about $400^{\circ}K$.

- The infrared radiometer showed essentially the same pattern of temperatures, with a pronounced limb-darkening effect.

- Both radiometers observed an anomaly along the southern part of the terminator: a cooler region, perhaps indicating a high surface feature disturbing the covering cloud structure.

- The data from Mariner is likely to yield significant improvement in calculations of the mass of Venus, the mass of the Moon, and the Astronomical Unit. The preliminary calculation for Venus: 0.81485 the mass of Earth, or 4.870×10^{24} kg, with an error probability of 0.015%.

MARINER IV

The most successful of the planetary probes flown by the U.S. to date, Mariner IV returned considerable data concerning Mars and interplanetary space in the antisolar direction.

This lineal descendant of Ranger and Mariner II traveled over 325 million miles in a 7½-month flight that produced 260 million bits of scientific and engineering data in a punishing performance that demanded 6,000 hours of life from 138,000 component parts in the rigorous space environment.

The versatile spacecraft took 21 pictures of Mars, revealing details of the Red planet never before seen from Earth. The 13½-hour encounter with the planet, with a 6,118-mile closest approach, yielded a significantly expanded insight into the interplanetary fields and asteroid and dust belts lying between Earth and Mars, the structure of Mars' fields and particles environment, the nature of its atmosphere, and a photographic basis from which to extrapolate something about the Martian surface topography.

<u>The preliminary record</u>. An early analysis of photographs and other data provides an interesting picture of Mars and its environment, and interplanetary space between the orbits of the two planets:

1. There was no measurable increase of cosmic dust particles near Mars. No well-defined dust streams were encountered during transit, although the flux seems to increase proportionate to the heliocentric distance from the Sun.

2. Mars apparently has no radiation belts, no evidence of trapped particles, and no magnetic field detectable at the distance of Mariner's trajectory. Thus, the Martian atmosphere and surface may be exposed to the full impact of solar and galactic cosmic radiation at all latitudes, a condition probably inimical to the existence of Earth-like life forms.

3. The atmosphere is extremely tenuous, with pressure at the surface estimated at about 5 millibars (Earth = 1,000 millibars at sea level), and the scale height somewhere around 30,000 feet. Thus, the Martian surface pressure is about 0.1 to 0.01 that at Earth's sea level. In this rare atmosphere, wind velocities must be particularly strong.

4. While Mariner IV's 21 photographs cover only one percent of the surface, they provide grounds for some fascinating theories:

   - Mars seems more like the Moon than the Earth. The 70 craters visible in photographs 5 to 15 vary in diameter from 3 to 75 miles and their structure and density are very similar to the upland areas of the Moon.

   - The state of erosion of the surface raises the probability that Mars is a most ancient planet--2 to 5 billion years old--still in its pristine state, and that it probably has never been subjected to the erosive force of large amounts of water or the internal stresses and deformation involved in Earth's evolutionary processes.

- There is no photographic evidence of mountain chains, valleys, ocean basins, or continental plates, and no definable trace of the celebrated Martian "canals".
- The Mariner photographs, covering only one percent of the surface, show a hostile, apparently waterless world with thin atmosphere and constantly bombarded by cosmic radiation, but they neither prove nor disprove the existence of life forms on Mars.

A continuing program. The Mariner Mars 1964 project was an outgrowth of decisions taken by NASA in 1962 authorizing the Jet Propulsion Laboratory to launch two spacecraft to Mars in the last two months of 1964. JPL was given project and mission responsibility, including management and development of the spacecraft, tracking, and data reduction and processing operations. Lewis Research Center was responsible for the launch vehicle effort.

An early decision was made to develop and build one proof test (engineering) model and three flight-qualified spacecraft and one set of selected spares. Launch was to be from the new Atlas D-Agena D vehicle, which would permit a 570-pound spacecraft weight. Mission constraints involved a 28-day launch period, with a 4-hour maximum launch window each day. Flight time would vary from 220 to 265 days, depending upon trajectory, with 10 additional days required for each transmission of stored data. New techniques involved a capability for performing two trajectory corrections, if required; S-band (2300-mc) communications system; use of the Sun and the star Canopus as attitude reference, and a spacecraft made as automatic in redundant reliability provisions as possible.

The primary objective of the missions was to conduct a close-up scientific survey of Mars during the "quiet" period of the Sun, perform certain fields and particles measurements in interplanetary space and in the immediate vicinity of the planet, transmit the data to Earth, provide experience in flying an attitude-stabilized spacecraft on a long-duration mission away from the Sun, and assure a probability of impacting the planet of not more than 1:10,000.

Epic journey. Mariner III, first of the two spacecraft scheduled for the 1964 Mars attempt, was launched on 5 November. When the plastic shroud failed soon after liftoff and could not be jettisoned, it was impossible to deploy the solar panels and the spacecraft systems were silenced when the battery failed after 8 hours and 43 minutes of flight.

Equipped with a new metal shroud, Mariner IV left the launch pad on 28 November 1964. The new Atlas-Agena D vehicle performed well and injection and separation were normal. Following separation, four solar panels were extended and the Sun was acquired. The spacecraft was allowed to roll gently for the next 15 hours while the magnetometer was calibrated against the structure's field in space. Then, the star Canopus was acquired, using an optical sensor whose axis was perpendicular to the spacecraft roll axis.

The first attempt at trajectory correction was cancelled when the star sensor lost lock on Canopus, probably because of a dust particle drifting across the field of view. Later, after this anomaly had occurred several times, the brightness response of the sensor was reduced by radio command, solving the problem.

On 5 December, the trajectory was successfully changed from a 156,000-mile miss to a fly-by of 6,118 miles above the south pole of Mars, with a change in flight angle of less than 1¼ degree and in velocity increment of 37 miles per hour.

During the first half of the mission, two-way communications were conducted with the low-gain omnidirectional antenna. The high-gain, body-fixed, directional antenna was switched in on 5 March 1965, when the beamwidth of the antenna intercepted the Earth, which remained within the antenna beam for the duration of the mission, stabilized by the Canopus sensor within 0.5 degree at all times.

On 11 February, the cover protecting the television optical system was dropped on radio command as a precaution against the dislodging of dust particles during the critical encounter phase.

During the long flight, only two discrete failures occurred in critical spacecraft systems. A component failure in the plasma probe in December made its data unintelligible until the switch in data rates in January 1965 effected partial recovery of data for the rest of the mission. The second failure occurred when the Geiger-Mueller tube of the ion chamber recorded a severe solar flare on 5 February and never fully recovered; it ceased functioning completely on 17 March.

Mariner IV encountered Mars on 15 July 1965. The planet was in view of the television subsystem for approximately 20 minutes, during which time 21 complete pictures were taken and recorded on magnetic tape. As the spacecraft passed behind the planet, it was occulted as seen from Earth, and remained so for 54 minutes, permitting subsequent analysis of the effect of the atmosphere and ionosphere on a radio signal, both while entering and emerging from occultation.

Following encounter, the spacecraft switched to a mode in which the stored photographs and science data were played back twice. These readouts alternated with intervals of real-time engineering data for ground tracking purposes. During the pre-encounter phases, the spacecraft had continuously transmitted commutated telemetry data, with 280 bits of science followed by 140 of engineering information.

The mission was terminated on 1 October 1965 with the spacecraft over 191 million miles from Earth. A series of monthly contacts has been scheduled since--that on 4 January 1966 successfully interrogating the spacecraft at 216 million miles, but without sending maneuvering commands. No attempt was made to read telemetry but the sidebands indicated that it was probably being transmitted. Round-trip time for the radio signal at the speed of light was 38 minutes 12 seconds. Another successful contact was made on 3 February 1966, with the spacecraft apparently responding to an Earth-based signal at a record distance of 213.5 million miles. When Mariner II returns within full communications range of the Earth in September 1967, it is planned to attempt a renewal of operations with the spacecraft.

An octagonal base. Although Mariner IV used much of the technology of Ranger and Mariner II, some modifications were made. The basic structure was an octagonal magnesium frame with seven bays used for mounting electronics cases and the eighth housing the propulsion system. Four erectable solar panels were attached to the top of the octagon, as was a fixed elliptical paraboloid antenna made of honeycomb aluminum. An 88-inch aluminum tube above the octagon supported a low-gain antenna at its top, the magnetometer, and the ion chamber-particle flux detector; it also acted as a waveguide for the omnidirectional antenna.

Mariner IV used the Sun and Canopus as references for attitude stabilization. Canopus, a bright first-magnitude star near the ecliptic pole, has a relatively unchanging geometry and experiences little interference from other stars. Power was supplied by 70 square feet of solar cells on four panels, producing regulated 2.4-kc, square-wave, and 400-cycle power, and unregulated DC for distribution to the subsystems.

Internal timing, sequencing, computing, and storage of commands were performed by a central computer and sequencer. A frequency reference, accurate to 0.01 percent, provided timing control. Attitude control was achieved in yaw, pitch, and roll by 12 jets at the outboard ends of the four solar panels, linked by logic circuits to three gyroscopes and the star and Sun sensors. Solar vanes at the ends of the panels provided back-up to the gas jet system for pitch and yaw control.

The RF subsystem used a single S-band, 2300-mc receiver that could be connected to either antenna. It operated coherently with the transmitters to provide angle tracking, doppler, and ranging data for orbit determination. Two types of RF amplifiers were available on-board: a 7-watt cavity amplifier and a traveling wave tube delivering 10 watts at S-band.

The standard Mariner-type propulsion subsystem was modified to provide the capability of two trajectory corrections to remove or reduce the allowable dispersions around the point of injection. The system used liquid monopropellant, anhydrous hydrazine in a gas-pressure-fed, 50-pound, constant-thrust rocket engine.

A command subsystem decoded Earth-originated radio commands, verified, and routed them to the proper using subsystems. The system could receive 29 Direct Commands for immediate execution, and one three-part Quantitative Command that was stored in the CC&S for delayed initiation.

A platform pointed 60 degrees from the roll axis on the under or shaded side of the octagon provided scan capability approximately at right angles to the relative motion of the spacecraft. The platform carried the television camera, which was designed so that, when the edge of the planet was sensed in the critical field of view, the scan would be stopped and the platform locked, allowing one continuous television sweep across the planet's disk. Output of the camera was stored in digital form on a magnetic tape recorder.

A data encoder provided formats, sequencing, and necessary analog-to-digital conversion for all engineering and scientific measurements originating in a 100-channel telemetering system. The science experiments were controlled and synchronized by a data automation system, which functioned both in real and non-real time.

<u>Science experiments</u>. Mariner IV carried seven science experiment packages and performed another experiment (occultation) which required no special instrumentation (Table 3). Of these, the television subsystem and helium magnetometer had never been flown before; the plasma probe,

Table 3. Mariner IV Scientific Experiments

Instrument	Purpose
Cosmic-Ray Telescope	To measure trapped radiation in the vicinity of Mars and the flux and energy of alpha particles and protons in interplanetary space.
Cosmic-Dust Detector	To measure dust-particle momentum and mass distribution in Earth-Moon, Mars-Deimos-Phobos, and interplanetary regions.
Trapped-Radiation Detector	To determine the distribution of energies and identify trapped particles in the vicinity of Mars and to monitor solar cosmic-ray and energetic electrons in interplanetary space.
Ionization Chamber	To measure the average omnidirectional flux of corpuscular radiation and the average specific ionization attributable to the flux between Earth and Mars and in the vicinity of Mars.
Plasma Probe	To measure spectral distribution and flux density of positively charged component of solar plasma.
Helium Magnetometer	To make vector field measurements of the magnetic field in the vicinity of Earth, in interplanetary space, and in vicinity of Mars.
Television	To make preliminary topographic reconnaissance of portions of the surface of Mars and to obtain additional data on Mars' surface reflectivities for the design of future systems.
Occultation	To improve estimates of the surface pressure, scale height, and other characteristics of the Martian atmosphere.

ion chamber-particle flux detector, trapped radiation detector, cosmic ray telescope, and cosmic dust detector had previous flight history.

The television camera, a Cassegrainian telescope configuration, was shuttered once each 48 seconds at 0.2-second speed, alternately exposed through green and red filters. The f/8 lens had a 12-inch effective focal length.

One of the most difficult problems was the extremely wide illumination range--from the bright limb of the planet to a point beyond the dark terminator region--compounded by uncertainty in tone illumination (or brightness) of Mars; these factors necessitated the use of automatic video gain adjustment. Distance and the low communications rate demanded a digital transmission system.

The helium vapor magnetometer, flown for the first time, operated on the principle that the transmissivity of light through a plasma of helium atoms in a metastable stage is a function of the angle between the light axis and the magnetic field in the plasma. The instrument can thus measure either interplanetary or planetary fields in three orthogonal axes.

FUTURE PLANETARY PROJECTS

In spring 1966, the United States was planning a program of exploration of the near planets and interplanetary space into the decade of the 1970's. A decision by NASA in January 1966 activated two new Mariner projects: one to take another, closer look at Venus in 1967, the second to return to Mars in 1969. Meanwhile, the Voyager Project will continue to prepare for planetary orbiters and perhaps capsule landers on Mars in the mid-1970 time scale. All of these projects are managed by JPL.

MARINER 1967

The Mariner 1967 spacecraft will draw heavily on Mariner IV hardware and technology, although some modification will be required because the mission will approach the Sun rather than fly away from it.

The launch schedule plans an early June 1967 liftoff with an Atlas-Agena configuration, and a Venus encounter about 19 October 1967, depending upon trajectory considerations.

Mariner 1967, weighing about 550 pounds, will attempt to approach Venus within 3,000 miles on a dark-side fly-by, compared with the 21,600-mile closest approach of Mariner II. Whereas the 1962 spacecraft did not detect any shock wave or other evidence of a magnetic field, it is hoped that the closer encounter in 1967 will identify shock waves in the magnetosphere of the planet, if it exists, and clarify our knowledge of the magnetic fields of Venus.

Mariner 1967 will carry an ultraviolet photometer for measuring atomic hydrogen and oxygen in the upper atmosphere, a trapped radiation detector, a plasma probe, and a magnetometer for investigating the fields and particles environment, both in transit space and in the vicinity of Venus.

Two RF occultation experiments will provide more of an insight into the structure of the Venusian atmosphere. As the spacecraft is occulted by the planet, relative to Earth, the S-band signal will pass through the atmosphere and be measured on Earth; in addition, two signals in harmonic relationship--50 and 450 mc--will be transmitted simultaneously to Mariner and stored on magnetic tape for post-encounter playback. The effects of the ionosphere and atmosphere of the planet on these transmissions will reveal considerable new information on the molecular density, scale height, and integrated electronic density of the planet's atmosphere.

The mission will include a sophisticated exercise in celestial dynamics: a highly refined analysis of trajectory data in relation to the motion and masses of the Moon and the planets of our system.

Because the motion of the spacecraft relative to the Sun is significantly different from that of Mariner IV, the solar panels must be reversed from the Mars mounting, and a smaller cell area is required. The radio transmitter will be essentially identical to that on Mariner IV. The low-gain antenna will be the same; design of the high-gain antenna has not been determined except that it must be modified to accommodate the S-band RF occultation experiment. The propulsion system will have the capability for two trajectory correction maneuvers.

MARINER 1969

The second phase of the extended Mariner series involves a two-spacecraft fly-by of Mars in 1969, using an Atlas-Centaur launch vehicle. The mission will largely be based on the Mariner Mars 1964 design and is intended not only to further the exploration of that planet, but to contribute where possible to development of the technology and implementation of the Voyager Project.

Mariner Mars 1969 is intended to make Mars-oriented measurements directed primarily toward the search for extraterrestrial life, and to develop the technologies required for the later Mars missions. Because of the planetary geometry in 1969, flight time will be approximately half that of the 1964 mission and the communications distance some 75 to 85 million miles, as compared with 150 million for Mariner IV. At encounter, the spacecraft will be considerably closer to the Sun than the 1964 mission.

Mars revisited. Current planning calls for increased planetary measurements during the mission. The scientific experiments being considered by NASA for preliminary design planning are:

- Improved television equipment--probably two cameras--to provide increased resolution and surface area coverage.
- A refined occultation experiment.
- An ultraviolet spectrometer to examine the atmosphere for ozone and free oxygen; or an infrared spectrometer to investigate absorption bands and other phenomena to determine water and carbohydrate content and to make an extrapolation of surface characteristics.

The launch vehicle will be essentially identical to that used for the Surveyor lunar missions: Atlas booster with high-energy Centaur second stage. The spacecraft will be in the 600- to 800-pound class, with the configuration for the most part the same as for Mariner IV, and the subsystems being changed only to accommodate the new mission requirements.

VOYAGER

NASA has designated the Jet Propulsion Laboratory to conduct the Voyager Project for long-range investigation of the solar system by unmanned spacecraft which will fly-by, orbit, or land survival capsules on the planets. Emphasis will be placed on obtaining information about the existence and nature of extra-terrestrial life; the atmosphere, surface, and body characteristics of the planets; and knowledge of the interplanetary medium obtained from scientific and engineering measurements made while the spacecraft is in transit.

Voyager will provide a flexible vehicle capable of different operational configurations while conducting experiments in exobiology and bioscience, planetology, the nature of the planetary atmospheres and their fields and particles environments, and solar physics and dynamics in relation to the physical processes by which the Sun influences the Earth and the other planets of our system.

Voyager is essentially an outgrowth of the residual effort that was focussed in the direction of Mariner follow-on in December 1964. Although a final design has not been adopted in early 1966, it is anticipated that the major systems will comprise a basic bus or structure, a retro-propulsion unit, and one or more landing capsules. The most recent planning calls for a 2,500-pound spacecraft bus, capsules weighing in the range of 3,000 to 10,000 pounds, and orbit-insertion propulsion of about 15,000 pounds. With the earlier, smaller capsules, the current plan is to launch two planetary vehicles of about 22,000 pounds each, in tandem from a single Saturn V vehicle. Suitable trajectory correction maneuvers will result in a two-week encounter separation at Mars.

With the extension of the Mariner-type projects through the 1969 Mars opportunity, first launch of Voyager would be scheduled for 1973, followed by other missions in 1975 and later. Although the details have not been determined, two spacecraft launched in tandem from the same vehicle would probably both be orbited around Mars, with a useful orbiting life of up to six Earth months or more. When the orbiting trajectory parameters are well defined, the capsule will be separated and landed on the surface to search for evidence of life forms and to make other scientific studies. The 1973 mission will probably require a capsule life of several days, which could be extended to several months for later flights, depending upon availability of a nuclear-powered generator.

Major problems. The principal problems facing the Voyager missions are: sterilization of capsule and scientific instruments; development of an effective communications system to operate either in a relay mode from surface to orbiting spacecraft, or directly from the landed capsule to Earth; significant increase in data storage and transmission capabilities; successful development of effective shielding methods and such nuclear power supplies as a radioisotope thermal generator; and design of a braking or retro-propulsion system compatible with the Mariner IV model of the Martian atmosphere: extremely low density and pressure, and violent wind velocities in the thin atmosphere.

The Voyager spacecraft must provide a communications and data storage capability several orders of magnitude higher than the 1964 Mariner design. The shielding technique must be developed and subsystems must be fundamentally less sensitive to radiation hazards. Larger, trainable antennas and increased power capacity will be necessary. The spacecraft propulsion system will probably have the capability for two or three trajectory correction maneuvers during transit; some terminal orbiting and entry operations will also be required.

The capsule will probably use some combination of aerodynamic braking, parachutes, and a retro-propulsion system for survivable and ultimate soft landings. A sophisticated attitude control subsystem and some form of radar altimeter control device will also be required eventually. An extended operational life on the surface will be necessary in order to gather scientific information relative to life forms and also to observe the effects of the changing Martian seasons. Some form of sterilization will be mandatory, perhaps involving clean-room assembly and a terminal heat application of about 135°C for 24 hours.

The 210-foot antennas of the deep space net will be fully operational for the Voyager missions. Although these facilities will dramatically increase the tracking and data recovery capabilities from Earth, the problem remains concerning relay or direct communications from the surface of Mars. Relay from the capsule and retransmission from the orbiting spacecraft would permit a higher data rate but would introduce problems of complexity and system reliability. Direct capsule-to-Earth communications would severely restrict the usable data rate without high-gain, directional antennas and a relatively high level of radiated RF power from the capsule.

BEYOND VOYAGER

Other than the approved Mariner Venus 1967, Mariner Mars 1969, and the Voyager projects of the 1970's, the United States does not as yet have a formalized or even uniquely defined program for exploration of the planets. Substantial effort is being expended in determining characteristics of potential candidate missions which would form the basis for any extension of the current projects.

The technological base, as a result of flights already accomplished, is considered to be rather substantial and the definition of a future program hinges more on programmatic decisions than on technological constraints. The many mission studies that have been conducted appear to subdivide future missions into three possible categories: Mariner class, Voyager class, and advanced interim spacecraft.

Mariner class. The Mariner class is defined as a mission whose scientific objectives are similar to those of Mariners previously flown or approved: an attitude-stabilized spacecraft capable of taking television pictures or their equivalent, such as ultraviolet or infrared maps, as a primary objective, with interplanetary fields and particles measurements as a secondary objective. Such spacecraft are capable of transmitting this data back to Earth from a distance of no more than one or two AU (Sun related). As already discussed, Mariners have been used successfully for both Mars and Venus probes, and can certainly be used again in this manner. In fact, it is considered within Mariner capability to add to the above characteristics the capability for an atmospheric entry probe, as in the case of either Venus or Mars, or perhaps a landed, although not necessarily survivable, capsule, in the case of Mars. In addition, however, it appears that such a spacecraft can be almost directly applicable to the exploration of certain nearby minor asteroids, such as Eros. The capability probably also exists, but perhaps with some revised temperature control subsystems, to perform early scientific missions to the planet Mercury. Finally, with perhaps relatively minor modifications, the Mariner spacecraft should also be capable of flying through the head or tail of a comet and examining the fields and particles characteristics, as well as searching for the presence of a solid nucleus.

The Mariner class of spacecraft probably cannot accomplish its type of scientific objectives at distances substantially beyond Mars (e.g., the outer planets). The limitation is, of course, the obvious one of maintaining a communications capability at such large distances. The accomplishment of these higher-energy missions is, therefore, relegated to the spacecraft discussed below.

Voyager class. The mission of the Voyager class of spacecraft is to perform scientific observations of a planet from an orbiter about that planet, and perhaps land a survivable capsule on the surface of the planet. The Voyager concept is considered to be an ultimate capability for planetary exploration for many years, perhaps decades, to come.

Shortly after its initial use for the exploration of Mars, it is planned to modify the orbiter as required for Venus missions and, thus, to embark upon a substantial exploration of that planet. Because of the high temperatures expected to exist on the surface of Venus, the United States is not currently planning survivable landers for such missions, pending confirmation or revision of the temperature estimate. Atmospheric entry probes or perhaps even landed but non-survivable capsules are, however, being seriously considered for Voyager Venus missions. Beyond its application to Venus, a Voyager orbiter with perhaps a survivable lander could be used for the exploration of the planet Mercury.

Sometime after extended exploration of the inner planets has been accomplished, it is likely that the Voyager spacecraft will be used for missions to the outer planets. Certainly the Mars version of the Voyager orbiter will have application to Jupiter and beyond with modifications probably no more complex than the replacement of solar cell power sources with some form of radioisotope thermal generator. The communications capability of the Voyager Mars orbiter is on the order of several thousand bits per second; the additional communications distance involved at Jupiter will undoubtedly still leave substantial capability.

After some small number of such Jupiter missions, it can be expected that a similar, if not identical, spacecraft can be used to explore the planets Saturn, Uranus, and Neptune. Missions to Pluto have not yet been studied. However, other missions to the major satellites of the outer planets will undoubtedly play a role in planning for this program.

Advanced interim spacecraft. In its current configuration, the Mariner class of spacecraft are not applicable to missions to the outer planets. The complexity, capability, and cost of the Voyager class will initially limit its use to Mars and Venus missions. Voyagers will not be used for the outer planets until, at the earliest, the late 1970's and perhaps not until after 1980.

Studies are currently underway to determine if a relatively inexpensive spacecraft can be designed for application without change to a wide variety of missions to the outer planets, asteroids, and comets. The scientific payload would be limited to 10 to 20 pounds and would be primarily concerned with the measurement of fields and particles. If such a spacecraft is feasible, it may be possible to measure some of the characteristics of these planetary objects with moderate expense. This data can then be used to develop missions utilizing Voyager spacecraft that will be capable of making more meaningful scientific investigations.

Recent technological accomplishments. In the year or so preceding this writing, two new approaches have shown promise for simplifying some of the spacecraft concepts discussed above: the use of gravity-assist (also known as swing-by) trajectories, and low-thrusted trajectories using solar electric propulsion principles.

It has been known for some years that the path of a spacecraft can be deviated by the control of its nearness of approach to an intermediate planetary target. The opinion had been, however, that the guidance requirements for such a gravity-assist intermediate encounter were quite stringent. More recently, however, trajectory sensitivity studies have indicated that the guidance requirements are achievable and, in some cases, can be adequately met by the use of Earth-based guidance alone. More specifically, the mission studies to date have centered on a Mercury fly-by with gravity-assist from Venus en route. It has been determined that the launch vehicle energy required for this combined mission is no greater than for a Venus mission alone: well within today's capabilities. A Mercury mission can be flown almost as a bonus to a Venus mission, except for the added expense and the compromises that must be made to select a payload with reasonable applicability for both planets.

Comparable trajectories using gravity-assist by the planet Jupiter to accomplish missions to the other outer planets have shown that savings in mission duration and launch vehicle energy can be obtained. Significant effort is still necessary in trajectory sensitivity analysis to verify that this type of mission will not be radically changed in guidance accuracy from that studied for Venus/Mercury missions. If this problem is adequately resolved, one can then expect to have a capability for exploring Saturn, Uranus, Neptune, and Pluto effectively when one has sufficient launch vehicle energy for missions to Jupiter.

The use of low-thrusted trajectories shows promise of simplifying the problem of reaching Jupiter. The principle of ion engine electric propulsion using a flight nuclear reactor as the power source has been under study for some years. The advantages of such a concept to a high-energy mission over the use of routine ballistic trajectories has been somewhat counterbalanced by the cost of development of a substantial flight nuclear reactor (electrical power on the order of 500 kilowatts).

Feasibility studies are currently under way to determine if solar photovoltaic power systems can be developed within the current state-of-the-art, and which can provide electrical power at a specific weight of less than 100 pounds per kilowatt. The initial results from these studies are encouraging. The attainment of this low a specific weight is considered to put the potential application of solar electric spacecraft into a very favorable comparison with standard ballistic means.

Additional studies and hardware feasibility determinations will be conducted. If the expected feasibility can be confirmed, solar electric principles will undoubtedly find application in future planning for planetary missions.